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INTERIM FINAL ENGINEERING REPORT
1-1/2 INCH ELECTROSTATIC
IMAGE DISSECTOR

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1. INTRODUCTION

The purpose of this program was to design and develop a small ruggedized electrostatic image dissector for use in star tracking applications. The tube was to be capable of sensing and resolving a 0.002 inch optical image with a total diameter flux of 10^{-8} lumens at the photocathode surface. A tube was designed around these requirements with an electron optical magnification near unity, an electron multiplier gain of greater than 1×10^{6}, electrostatic focusing, and with electrostatic deflection capabilities in two orthogonal axes. The design made use of sealed glass-to-metal envelope sub-assemblies to achieve greater ruggedization than would be afforded by a one piece envelope construction, which depends upon numerous internal spot welded spacers and supports for mounting of the electron lenses and multiplier structure.

The front end design was made flexible to enable the use of either spherical clear glass or plano-concave fiber optics entrance windows in the event that a flat optical image plane proved desirable in the star tracking application. In the initial design, a 0.002 inch circular aperture was employed to enable tube evaluation to be performed using test procedures similar to those used in the evaluation of standard camera tubes. During the course of the program, many changes in aperture geometry, electron optical design and processing techniques were made to improve the image dissector tube for use in its end application.

Initial camera tube test procedures were found inadequate for complete evaluation of the image dissector for the intended application. Numerous changes in test procedures and electrical specifications were made as the needs became apparent. The original and modified specifications and test procedures are described in this report.

Early attempts were made to incorporate a bi-alkali photocathode in the image dissector to enable the device to be subjected to temperature sterilization procedures. These efforts were unsuccessful in the time available for experimentation. Relaxation of the thermal environmental requirements led to the use of an S-11 photosurface in the image dissectors. It is believed at this time that further experimentation would result in favorable formation of a bi-alkali photocathode in this tube.

To increase the environmental reliability and resistance to external magnetic fields and to provide ease of mounting in the star tracker assembly, the image dissector was potted within a Mu-Metal housing with front and rear mounting rings. Eighteen tubes were delivered to JPL during the course of the program.

2. OPERATION OF THE ELECTROSTATIC IMAGE DISSECTOR

The operation of the image dissector, developed under this program, is described briefly below. An optical image (in this application, a star image) which is formed at the entrance window of the image dissector is converted to an electronic image at the photoemissive cathode deposited on the inside surface of the window, (See Figure 1). The electronic image consists of photoelectrons emitted from the cathode surface with varying densities dependent upon the magnitude of incident illumination; i.e., the greatest number of photoelectrons are emitted from that portion of the image corresponding to the maximum illumination area of the optical input and no photoelectrons are emitted from areas corresponding to the black portions of the aerial image. The photoelectrons generated at the photocathode are accelerated and electron optically focused on the plane of an electron aperture so that an image of the current distribution at the photocathode is formed in the plane of the aperture plate. If the imaging section were to be coupled to a phosphor screen instead of an aperture plate, an inverted optical image would be visible in the focal plane. However, with a solid plate, having a small aperture at its center, only that portion of the electronic image which is formed directly over the aperture is permitted to pass through the aperture. By incorporating a deflection system between the photocathode and aperture electrodes, the electronic image may be swept across the aperture allowing each segment of the image, equal in size to the aperture, to pass sequentially through the aperture.

Knowledge of the deflection program provides sufficient information to associate each segment of the electronic image with the corresponding segment of the optical image. By the introduction of an electron multiplier behind the image section, the electronic signal passing through the aperture is amplified to a readily measurable level.

Having thus described other operating principles of the electrostatic image dissector, we shall pass now to an account of the development of each section of the tube.

3. ELECTRON OPTICAL DESIGN OF IMAGE SECTION

The electron optical design of the image dissector was established by calculations based on a two electrode, concentric sphere electron optical focussing system [1,2]. The sizes and spacings of the electron optical lenses were chosen to give a magnification of approximately 1:1 for the imaging section.

A cylindrical focusing electrode was incorporated in the image section to allow compensation for deviations in electron lens alignment and departure from true spherical geometry caused by the cylindrical wall of the tube envelope. Figure 1 shows the image dissector configuration.

The photocathode and the small end of the anode cone, which houses the deflection system, are the concentric spherical elements which determine the electron optical characteristics. The geometry of these elements determines the magnification and focal plane of the image section.

The initial electron optical design, which is shown in CBS Drawing NO. 20298, Appendix I, was found to impose a severe limitation in the viewing angle and off-axis spot resolution capabilities of the tube. The limitations were believed to be caused by the following effects:

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1. P. Schagen, H. Bruining, and J.C. Fracken, Phillips Res. Rep. Vol. 7, pp. 119-130, April 1952

2. B.R. Linden and P.A. Snell, Proc. IRE, Vol. 45, pp. 513-523, April, 1957

1. Deflection defocusing, resulting from the close proximity of entering electrons to the deflection plate fringe fields at the small end opening of the deflection cone. Incident electrons thus experience varying forces, dependent upon the location and angle of exit from the photocathode.

2. The small diameter of the anode cone entrance, resulting in electron collection by the anode cone. This effect, again, is a function of the electron position and angle of emission from the photocathode.

3. The close spacing between the cylindrical wall of the focusing electrode and the photocathode. This condition results in strong field distortion, which causes electrons emitted from off-axis locations of the photocathode to traverse non-spherical equipotential surfaces and hence be accelerated toward the anode cone electrode, rather than the aperture therein.

These conditions are shown schematically in Figure 2, which is a field and electron trajectory plot for the initial image dissector design. The plot was made by resistive paper techniques, which is not directly applicable, but is analogous to systems with cylindrical geometry and provides useful comparative information. The figure shows trajectories of electrons emitted from the center of the photocathode at an angle of 30° with respect to the normal and from an off-axis point with emission normal to the photocathode surface and at a 30° angle with respect to the normal. The figure indicates that the electron bundle emitted from the off-axis location is widespread and is directed by and large toward the surface of the anode cone, thus accounting for limitations in viewing angle and off-axis resolution. It will be noted that the trajectory for electrons emitted at 30° with respect to the normal toward the cylindrical wall has not been included. It is, however, apparent that such electrons would be directed even further away from the anode cone entrance and would show a wider spread in the electron bundle.

To improve the electron optical performance, the geometries of the three elements discussed above were altered as follows:

1. The deflection cone entrance was increased in diameter by shortening the deflection plates. This reduced the fringe field effects on the entering photoelectrons.

2. The anode cone spherical radius and entrance diameter were increased to prevent collection of incident electrons by this electrode.

3. The distance between the focusing electrode and the photocathode was increased in order to reduce the field distortion and allow the off-axis electrons to be better directed toward the anode cone entrance.

The resulting field and electron trajectory plot is given in Figure 3. The improvement in field shipe and electron bundle cross section are apparent by comparison of the above figures. Test data on experimental tubes confirm the results obtained above.

The final design is shown and detailed in CBS Drawing No. 08-764, Appendix II.

4. FIBER OPTICS

The fiber optics faceplates used in the image dissector were made of a lanthanum type glass with a numerical aperture of 0.84. The fibers are 7 microns in size and each fiber is surrounded by a dark cladding (called extra mural absorption and usually referred to as EMA). The cladding prevents optical cross talk between fibers and thereby improves the resolving power of the plate. To protect the lanthanum fibers from injurious effects of the alkali elements used in the tube processing, a thin non-lead vitreous overlay was subsequently applied to the surface of the fiber optic window.

The fiber optics vendor provided information on optical transmission through the fiber optics as a function of angle of incidence. This data is tabulated below:

7 MICRON FIBER SIZE WITH EMA

Viewing Angle	Transmission
± 30°	88%
± 45°	65%
± 50°	50%
± 60°	27%
± 70°	10%

//

7 MICRON FIBER SIZE WITHOUT EMA

Viewing Angle	Transmission
± 30°	83%
± 40°	70%
± 50°	64%
± 60°	49%
± 70°	32%

It was found that standard fiber optics windows exhibited dead spots, having a diameter of 0.004 inch. A spot of this size in the useful area of the photocathode would cause serious non-uniformities in tube response, since the optical input (star image) is 0.002 inch diameter.

With the co-operation of the vendor the following specification was established. The selected central area, 0.170 inch by 0.590 inch, should contain no dead spots greater in equivalent area than a 0.0015 inch diameter circle. A dead spot being defined as any area having less than 50% transmission relative to the average transmission of the faceplate.

To limit the total field of view all but a central rectangular area of the outside of the faceplate, 0.160 inch by 0.570 inch was coated with an opaque vacuum deposited aluminum film. This effectively reduced the background and the possibility of acquiring unwanted signals. Initially, the aluminum film was to be coated with a vacuum deposited layer of silicon monoxide to protect the film against abrasion. However, it was found that when the aluminum film deposited on the window was oxidized in air at an elevated temperature, the resistance to abrasion was high. Surfaces treated in this manner yielded greater surface strength than was obtainable with the former silicon application.

Tests previously performed on standard photomultiplier tubes reportedly indicated that operation of the tube with a potential difference across the tube window resulted in photocathode degradation.

The contractor was concerned that the image dissector may suffer from similar degradation, since in this particular application, the outer surface of the fiber optics could charge up to a potential of +700 volts, with respect to the inner (photocathode) surface. To prevent reactions of this nature, a transparent tin oxide conductive coating was applied to the exterior of the fiber optics window. This coating is electrically connected to the photocathode flange, by means of conductive paint, and held the outer surface of the window at the potential of the photocathode.

Use of the conductive coating presented serious problems, in that surface imperfections in the fiber optics core material developed during the tube processing cycles. The imperfections occurred as a result of chemical inter-action between the lanthanum glass and the tin oxide. Subsequent experiments, indicated that spot degradation of the fiber optics was caused by reactive tin compound globules which occurred randomly across the faceplate during deposition. The heavy globules remained sufficiently active to cause surface corrosion during further window handling. Many experiments were performed to alleviate the formation of globules in the coating operation. Coated fiber optics samples were subjected to temperature and humidity exposures in an effort to test the surface quality in an accelerated manner. The numerous experiments showed that the conductive coating deposited directly on the fiber optics material, withstood the environmental exposures better than that deposited on the vitreous overlay. Significant improvement was achieved with a revised technique including the following steps:

1. Filtration of the coating solution.

2. Improved mounting of fiber optics faceplates in the processing oven.

3. The use of gauze baffles in the hot zone of the oven, between the vapor source and the fiber optic faceplate.

4. Use of a clean, disposable oven liner for each coating operation.

No severe surface degradation developed in any of the fiber optics windows used since the improved coating techniques was employed.

5. THE IMAGE DEFLECTION SYSTEM

To dissect the electronic image of the photocathode it is necessary to scan the image across the aperture which is in the focal plane of the electron lens system. Since the image dissector was for use in space vehicles, the deflection system had to satisfy the following requirements:

1. The power consumption was to be low.
2. The weight and size was to be a minimum, and
3. The structure had to be capable of withstanding severe environmental stresses.

(1) and (2) precluded the use of a magnetic deflection system, and therefore an electrostatic deflection system was required.

The deflectron[3], electrostatic deflection system was used since this approach was the only one which could satisfy all of the above requirements.

In addition, the deflectron permits bi-axial deflection from a common center with much less scan distortion and at greater angles than conventional electrostatic deflection systems.

The deflectrons were made of truncated hollow glass cones with four specially designed metal electrodes deposited on the inner surface. Metal pins sealed in the cone wall provide electrical connections to the deflection plates. Figure 4 shows the shape of the electrodes and the electrical connections. Figure 5 serves to illustrate the good linearity of the deflection design.

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3. Dr. Kurt Schlesinger, Proc. IRE, Vol. 44, pp 659-667, May, 1956

6. THE ELECTRON MULTIPLIER DESIGN

The well proven CBS twelve stage linear focussed type of electron multiplier was selected for use in the image dissector tube.

This structure was capable of fulfilling the electrical performance requirements and was small enough to be mounted with the restricted limits of the tube envelope. In addition, since this type of a structure has a relatively long (5/8") dynode it offered the possibility of improved uniformity when used with long image section apertures.

A typical applied voltage versus gain curve of the 12 stage CBS linear focussed electron multiplier is shown in Figure 6.

7. MECHANICAL DESIGN

7.1 Envelope

The 1 1/2 inch diameter image dissector envelope assembly was designed in three sections, namely the window section, the deflection body and the multiplier section. Each section utilizes glass-to-metal seal construction which permits rugged mounting of internal metal parts and allows electrical connections in the image section to be made through the metal components. This design significantly reduces the number of connections required in the stem header and the associated electrical insulation problems. The faceplate section was designed in such a way that either 7052 glass windows or fiber optics faceplates could be installed with no further design modifications. The sealing requirements for these two windows are different in that the co-efficients of expansion are not the same, and hence different metals are required for sealing. To accommodate both sealing requirements the window ring was designed in two parts. The outer part made of Kovar, is sealed to the 7052 glass envelope. The material of the inner ring section is chosen to fulfill the sealing requirements of the window to be used. The final vacuum seal in the window section is accomplished by a heli-arc weld between the inner and outer window rings.

The deflection body, made of Kovar rings sealed to a center section of 7052 glass, houses the electron optical lenses and the deflection system. Kovar pins are sealed through the cylindrical wall of the glass section to provide electrical connections to the deflection plates. The multiplier section is composed of a Kovar ring sealed at one end of a 7052 glass cylinder and a 12 lead hard glass stem sealed at the opposite end. The sub-assemblies are heli-arc welded at the metal flange interfaces to form a vacuum tight envelope enclosure.

7.2 Image Section

The image section comprises the photocathode, focus electrode, anode cone, and deflectron cone, electrodes. With the exception of the photocathode, these elements are mounted in the deflection body envelope section. The focusing electrode contains the heaters used in evaporating the photocathode substrate materials. This electrode is spot welded within the upper Kovar ring in the deflection body envelope. The spot welding provides the mechanical bond as well as the electrical connection between the lens elements and the envelope flange.

The glass deflectron cone is secured within the anode cone via spot welds to insulator feed throughs. The cone assembly is located by fixtures and is spot welded within the lower ring of the deflection body envelope.

Electrical connections to the deflection plates are made through nickel ribbon, which is spot welded to the deflectron cone and deflection body pins. The electrical connection to the anode cone electrode is made through the envelope flange. Both the anode cone and focusing electrode positions are aligned with reference to one flange of the deflection body envelope by means of mounting jigs and fixtures.

7.3 Electron Multiplier Section

The multiplier section consists of a 12 stage, focused type electron multiplier and an aperture plate, housed within the multiplier envelope section discussed earlier. The electron optical design of the multiplier is the same as that used in standard CBS photomultiplier tubes. The secondary emissive material used in the focused structure is silver magnesium. The photoceram support insulators used for dynode mounting were specially designed for the image dissector to accommodate the 12 multiplier stages required to achieve a gain 1×10^6. The first dynode is secured to a metal top shield which also serves to position and contain the aperture plate. Spot welded connections to the dynode cross wires provide support for the lower end of the multiplier structure and electrical connections through a glass-to-metal sealed stem assembly. The upper end of the multiplier is secured by a slip fit and spot welds between the top shield and envelope flange.

As indicated previously, the tube assembly is formed by heliarc welding the envelope flange interfaces, providing mechanical and vacuum tight seals.

8. TUBE MANUFACTURE

8.1 The Photocathode Substrate

Initial tubes manufactured under this program were made with a 0.002 inch diameter circular aperture, a clear glass spherical window, and an S-11 photocathode. Since it was expected that current loading at the photocathode might cause long term cathode degradation, a transparent conductive coating was deposited on the inner surface faceplate prior to tube assembly. It was found in tubes using this substrate, that the photocathode sensitivity was, in general, lower than anticipated. It was believed that this occurred primarily as a result of interactions between the cathode and substrate materials, although some light attenuation was caused by the absorption of the transparent conductive coating. After sufficient performance data was collected by the contractor and these laboratories, it was determined that the conductive substrate was not required for this application. Therefore, photocathodes were deposited directly on the window surface in all further tubes.

8.2 Sealing And Welding

During the early phases of the program difficulties arose in the window sealing and heli-arc welding operation. Induction heating techniques were employed to effect the seal between the glass window and the metal window ring. Considerable experimentation led to satisfactory pre-seal and sealing temperature control, by the use of carbon fixtures to maintain uniformity of heat. Two annealing cycles were required, one performed immediately in the window sealing apparatus and one in a controlled annealing oven, to prevent window strains and later fractures from occurring.

Early in the program, much difficulty was encountered in welding the three tube sections together. It was found that the major cause was excessive heating in the welding procedure. Experimentation to determine optimum weld time and current requirements resulted in vacuum tight welds with no glass breakage.

8.3 The Deflectron

As indicated previously, a Deflectron deflection system was used. Two Deflectron fabrication techniques were investigated to determine the best approach. The techniques investigated were as follows:

1. Pattern transfer
2. Photo-etching

8.3.1 Pattern Transfer

In the pattern transfer technique, a silver deflection plate pattern is silk screened onto a transfer paper. The pattern is then transferred to the inside surface of the glass cone by mechanical means. Initial attempts were unsuccessful, since the pattern would not adhere to the glass surface during the required temperature cycling needed to center the patterns to the cone. In addition, pattern definition was poor.

In further experimentation with the transfer process, it was determined that the problems formerly encountered with this process were associated with the type and consistency of the silver paint used in the silk screening operation, as well as the type of transfer paper employed. Experiments performed with various combinations of paints and transfer papers yielded a useful technique. The revised transfer technique was used in all tubes to the completion of the program.

8.3.2 Photo-Etching

In the photo-etching method of plate deposition the inner surface of the cone was first coated with a metal and then a photo-resist. The resist was then exposed to a light through a suitable mark and then the unexposed areas were disolved in a suitable developer. The unprotected metal was then etched away. Finally the exposed photoresist was dissolved leaving the deflection pattern in the cone.

This method initially appeared to be the most promising approach. However, cones made by this technique exhibited extremely poor pattern definition and displayed high ohmic leakage between deflection plates. Repeated attempts to obtain higher deflectron quality were unsuccessful.

8.4 Photocathode

It was planned in the early phases of the program to incorporate a high temperature (bi-alkali) photocathode in the image dissector. The photocathode substrate was to be a tin oxide conductive coating. Unsuccessful results in the formation of this photocathode were attributed to a possible incompatibility between the photocathode and tin oxide materials. Further bi-alkali experiments without tin oxide yielded satisfactory photocathodes in standard photomultipliers, but no success was experienced in adapting these techniques to the image dissector geometry. As a result of pressing time limitations and a relaxation in the temperature requirements for the tracker system, bi-alkali experimentation was discontinued and the image dissectors were made with S-11 photocathodes.

Continuing experience in the manufacture of the image dissector led to improvements in processing techniques. In general, the photocathode sensitivities progressively improved during the course of the program. In addition, photocathode uniformity, which previously suffered due to ion feed-back to the photocathode, was greatly improved by the following changes in the formation procedure.

1. Process heater locations were altered to provide better shielding of the anode cone electrode from antimony evaporation. This reduced the amount of cesium collected in this location and hence eliminated one source of cesium ion release during tube operation.

2. The outgassing bake temperature was reduced to prevent undesirable migration of antimony.

3. The outgassing time was increased to approximately 20 hours to minimize evolution of occluded gasses during later operation of the tube.

4. An ion pump was attached to each tube to enable continuous pumping during initial operation of the tube. The tubes were exposed to an operational ageing cycle, starting with a low intensity light input, which is slowly increased (maintaining a hard vacuum within the tube) to a level which is equal to or greater than that to which the tube is ultimately exposed, in most cases 10 foot candles. The tubes are operated under these conditions for extended periods to ensure good final pressure.

Changes in the method of cesium introduction, i.e., the use of an electrically resistive cesium generator in addition to a cesium capsule which is activated by induction heating, significantly reduced inter-element ohmic leakages within the image dissector. The greatest improvement was achieved in the deflection system region.

8.5 Electron Multiplier Mounting

In the later part of the program, difficulties were encountered with the 12 lead stem. Lead wire bending is required in this area to accommodate the final vacuum seal-off at the glass tubulation which is located at the center of the stem. The leads later require straightening for insertion in the divider module which is affixed to the back end of the image dissector. During these bending operations, several tubes experienced broken stem leads. The .020 inch diameter wires were previously weakened by the extreme temperature exposures experienced in the glass stem sealing operation. In addition, several vibration failures occurred as a result of open butt welds in the nickel to Kovar stem leads. To prevent reoccurrences of these problems, the former stems were replaced by stems with straight through .025 inch diameter Kovar wires in all further tubes. No difficulties have arisen since the new stem design was adopted.

8.6 Ruggedization

Near the end of the program, mechanical failures occurred in several image dissectors. The failures were described as follows:

1. Open circuits occurred in the butt-welded stem leads. As indicated previously, the butt-welded leads in later tubes were replaced by straight through Kovar wires.

2. In one tube the focus electrode became loose during vibration. To prevent further occurrences of this problem, the method of mounting this electrode was changed. Slots were cut in the cylindrical mounting wall of the focus electrode to provide sprung tabs for improved welding to the focus electrode ring. This enabled a superior mechanical bond for the focusing element.

3. One or two dynode lead wire connections became open circuited during vibration. To reduce possibilities of mechanical failures, a weld schedule development program was performed to establish optimum weld conditions for each weld in the image dissectors made under associated programs. Initially, a weld schedule development procedure based on establishment of iso-strength diagrams for each weld in the assembly, coupled with visual observations under 15X magnification was used to insure suitable weld strength, ductility, wire set-down and deformation was used. With this method, coarse mesh curves of pull strength versus weld energy are developed for constant welding forces. Repeated measurements at varied weld forces yield a family of curves describing pull strength as a function of energy and weld force. Analysis of the curves permits selection of areas which afford the minimum variation in weld strength over the widest range of weld energy and force conditions. Coupled with visual observations, this gives sufficient information to choose the optimum range in which to run a fine mesh sampling. A quantity of 5-10 weld samples is made at each set of conditions in this range to determine the optimum point.

This method was employed in the weld development for critical wire-to-wire welds, but due to the time factor involved, a considerably less detailed method was used for the remainder of the weld combinations. In all, combining the iso-strength diagram and accelerated methods, 45 weld schedules were developed. These schedules were employed in the manufacture of tubes in related programs.

8.7 Results

Eighteen (18) operable tubes with a variety of aperture sizes were delivered to JPL during the program. The performance figures of the last five are shown in Table I.

Tube No.	P.C. Sensit. µa/l	P.C. Unif. %	Deflect Sensit. V/in/KV	Multip. Gain	Dynode Unif. %	Response Unif. %	Dark Current Anode µ/a
2493ZA	44.6	90	N.M.	9.75×10^5	N.M.	N.M.	.016.
2537ZA	29.6	N.M.	N.M.	4.18×10^6	N.M.	N.M.	.08
2678ZA	43	90	797	7×10^6	96	95	.04
2786ZA	34.2	78	886	16.3×10^6	97	95.5	.04
3066ZA	39	91	800	4.38×10^6	95.4	89	.04

N.M. Not measured due to rejection for other specifications.

µa/l microamperes per lumen

µa microamperes

V/in/K volts per inch kilovolt

The resolving power of the tube is indicated in the electronic spot size versus image displacement are in Figure 8.

The major problems encountered in the manufacture of the tubes close to the final design were:

1. Vacuum leaks - The rugged design and the limitations of physical size made the use of extensive glass-to-metal seals mandatory and very close control of the glass-to-metal sealing and seal preparation techniques was necessary. The use of well designed heat sinks and short heat cycles eliminated leaks due to the introduction of stresses in the heli-arc welding operations.

2. Fiber optic conductive coating - This subject was fully discussed in Section 4.

3. Alignment of the deflection axes with the rectangular aperture. Electronic equipment was built so that the electronic axes of the deflectron could be determined, however, with subsequent improvements in jigs, the optical alignment method proved to be more consistent.

9. TESTING & EVALUATION

9.1 In the early stages of the program the following characteristics were determined:

9.1.1 Photocathode Sensitivity - Microamperes/lumen

This was measured using a calibrated 2870°K tungsten source and with all other electrodes in the tube 300 volts positive with respect to the photocathode.

9.1.2 Gain

The tube was energized with 1200 volts on the image section and 105/stage on the multiplier section. The overall sensitivity of the tube was then measured with a calibrated light input. The gain of the electron multiplier was calculated by equating the area of the aperture to the area of the photocathode and the overall sensitivity of the tube to the photocathode sensitivity. Early measurements were not indicative of the tube's performance until the necessity of performing this test with the focus electrode at its operation potential was determined.

9.1.3 Signal-to-Noise Measurements

Signal-to-noise measurements were made with the same applied voltages as in 9.1.2. A 0.0005" diameter, 10^{-8} lumen image was projected onto the photocathode and a saw tooth sweep applied to one set of deflection plates. The deflection in the orthogonal axis was controlled so that the electron image swept across the aperture. With the focussing electrode potential adjusted for maximum resolution, the peak signal and the noise-in-signal was measured. From this the signal-to-noise ratio was determined.

9.1.4 Resolution

The resolution of the Image Dissector was measured with the tube energized as in 9.1.3. A demagnified image of a high contrast bar chart for calibrated groups of 7, 10, 14, 20, and 28 lines per millimeter was imaged to the cathode. The 20 lines per millimeter group represented 500 TV lines per inch or 0.002 inch resolution. The long axis of the bars was set parallel to the unswept deflection axis. A saw tooth sweep was applied to the orthogonal deflection axis and the anode output across a load resistor was displayed on a cathode ray oscilloscope. The resolution was taken as the group of lines having 50 percent contrast.

9.1.5 Deflection Linearity

With a tube energized as in 9.1.2 an optical image 0.002 inch in diameter was located at a series of positions from 0 to 0.25 inch either side of the center of the tube in the direction of the deflection to be measured. The deflection potential required for the deflection of the electron image to the center of the aperture was recorded for each position. The linearity was then represented by plotting the position of the optical input against the deflection potential.

9.1.6 Photocathode Uniformity

Photocathode uniformity was measured with the image dissector connected as in 9.1.2. A saw tooth deflection sweep was applied to one set of deflection plates and a manual control to the other. The output of the tube across a load resistor was observed by a cathode ray oscilloscope. By use of the manual control the sensitivity of each portion of the cathode was observed.

9.2 Final Test Procedures

During the later phases of the program, other tests with a closer relationship to the proposed tube application were developed. The specifications and the test for confirming these specifications are included in Appendix III.

10. TUBE ENCAPSULATION

In the early phases of the program, methods of encapsulating the completed tubes were investigated. Later it was decided that the design of the encapsulating should be undertaken by JPL so that the manner of mounting and the tube placement in relation to other electrical and optical components of the tracker could be readily taken into consideration. Later in the program, tubes were encapsulated with fittings which were designed to permit the ready replacement and accurate alignment of the tube in the star tracker assembly. Figure 7 is a photograph of the encapsulated tube.

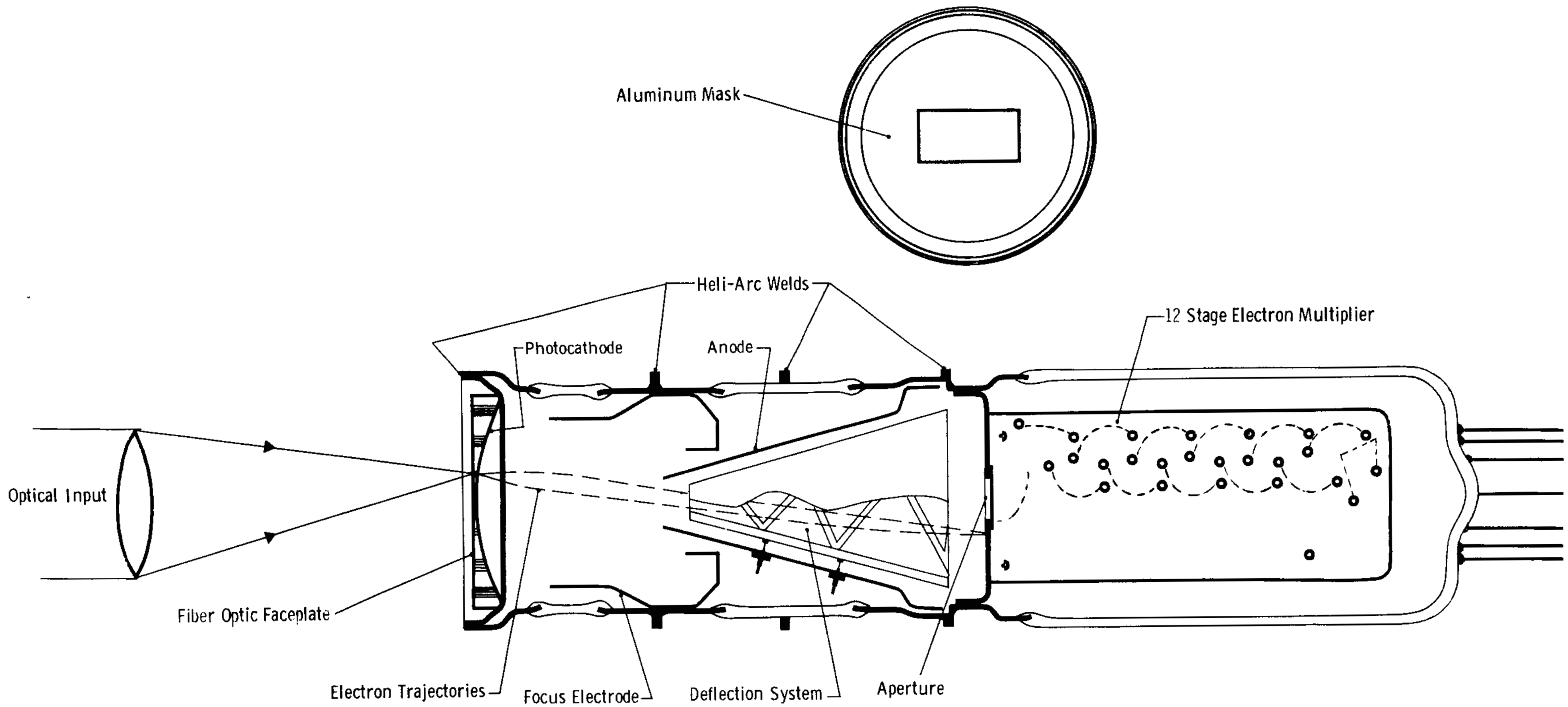
In the encapsulating procedures, the faceplate and the electron multiplier ends of the tube were accurately mounted within cylindrical glass fiber re-enforced epoxy resin fixtures so that the axis of the fittings was perpendicular to the outer surface of the faceplate. Spaces between the fittings and the tube which were designed to allow for tube manufacturing tolerances were then filled with encapsulating compounds and the whole was allowed to cure while being held in position by the alignment fixtures. On completion of the curing cycle, the tube was removed from the fixtures and an additional split cylindrical collar was accurately mounted by similar means to the aperture plate mounting rings in the mid-section of the tube. A resistor network module was then welded to the electron multiplier leads and encapsulated in position at the stem end of the tube.

Magnetic shields with suitable terminations and holes for previously attached electrical connections were then mounted with encapsulating compounds and screwed to the cylindrical part and the electron multiplier end of the assembly.

11. CONCLUSION

The design and development of a small rugged electrostatically deflected and focussed image dissector was successfully accomplished.

The feasibility of using a deflectron electrostatic deflection system in a small image dissector tube was established.



THE IMAGE DISSECTOR TUBE

Figure 1

Field and Electron Trajectory Plot
1-1/2 Image Dissector
Narrow Viewing Angle

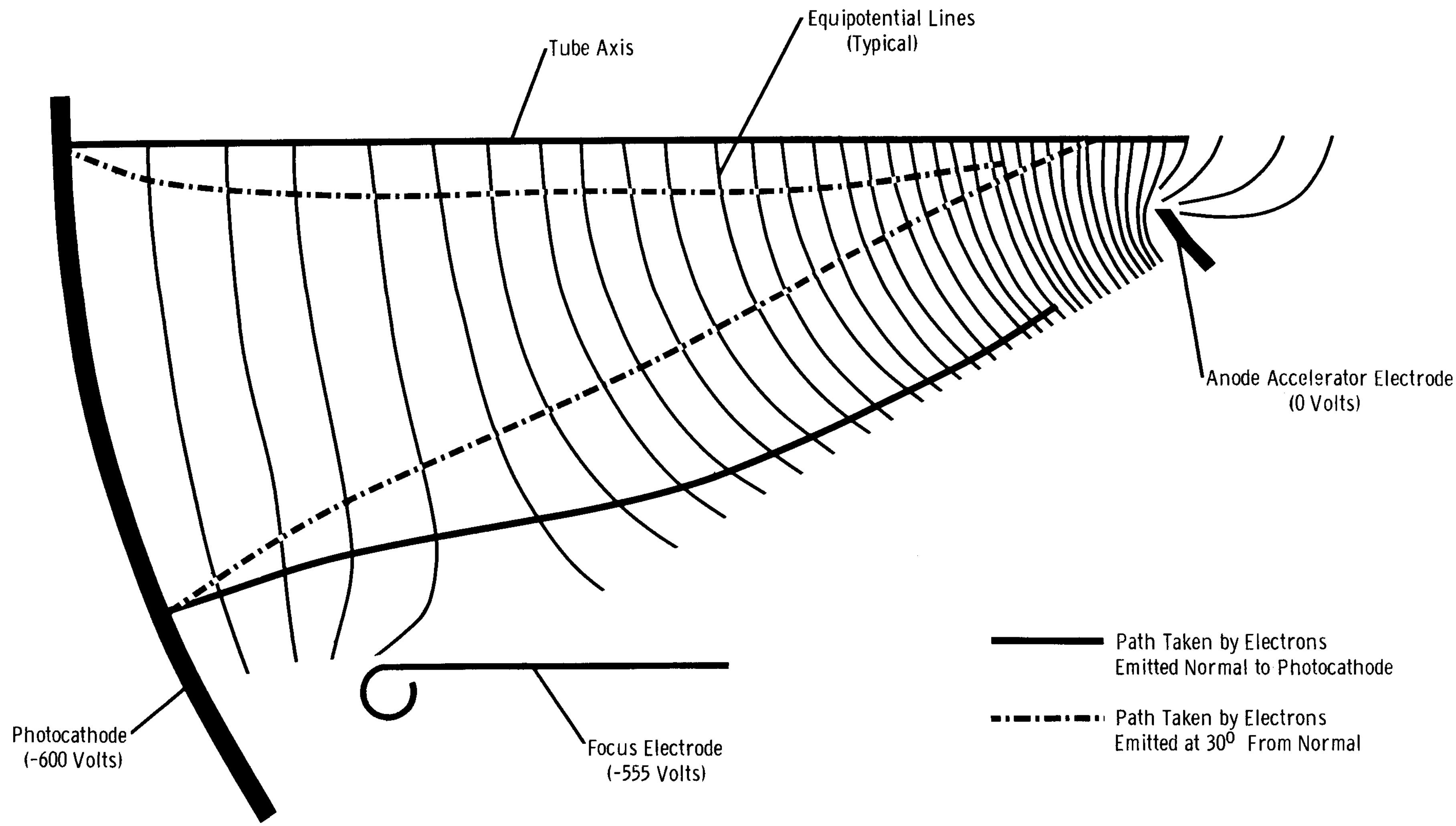


Figure 2

Field and Electron Trajectory Plot
1-1/2 Image Dissector
Wide Viewing Angle

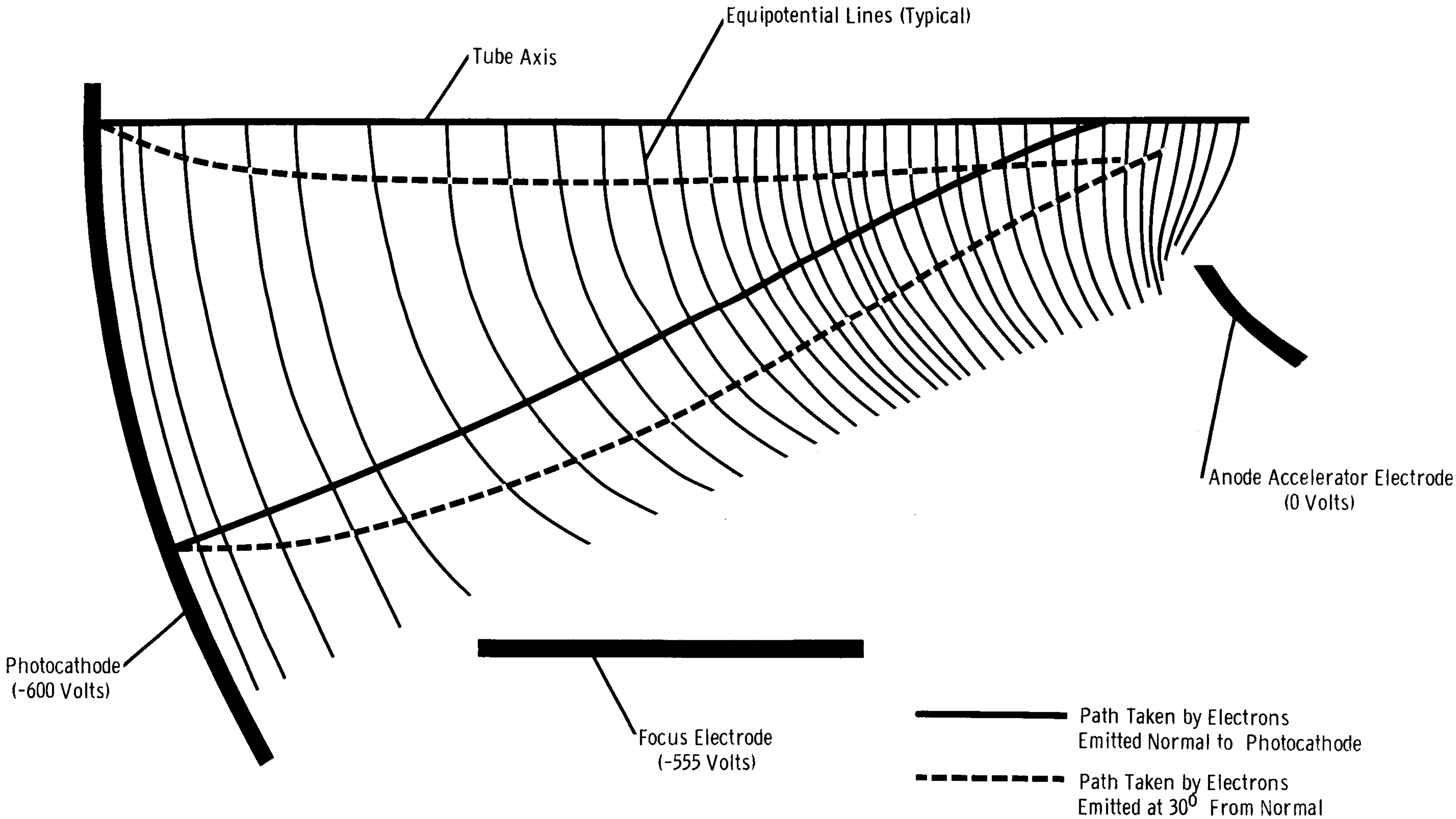


Figure 3

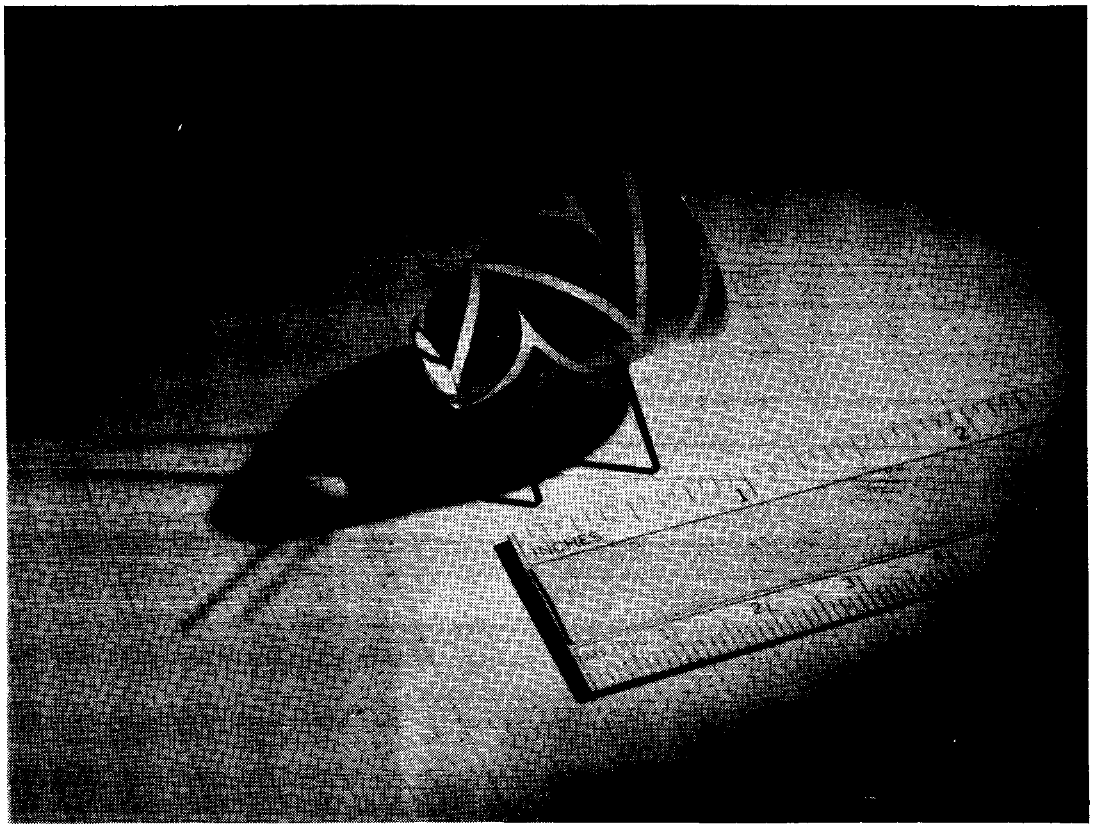


Figure 4

Deflectron Cone

TYPICAL DEFLECTION LINEARITY CHARACTERISTICS

CONDITIONS:

0 VOLTS — ANODE APERT. PLATE
0 VOLTS — STATIC PT. — VERT. PLATES
0 VOLTS — STATIC PT. — HORIZ. PLATES
−600 VOLTS — PHOTOCATHODE TO APERT. PLATE
−555 VOLTS — FOCUS TO APERT. PLATE

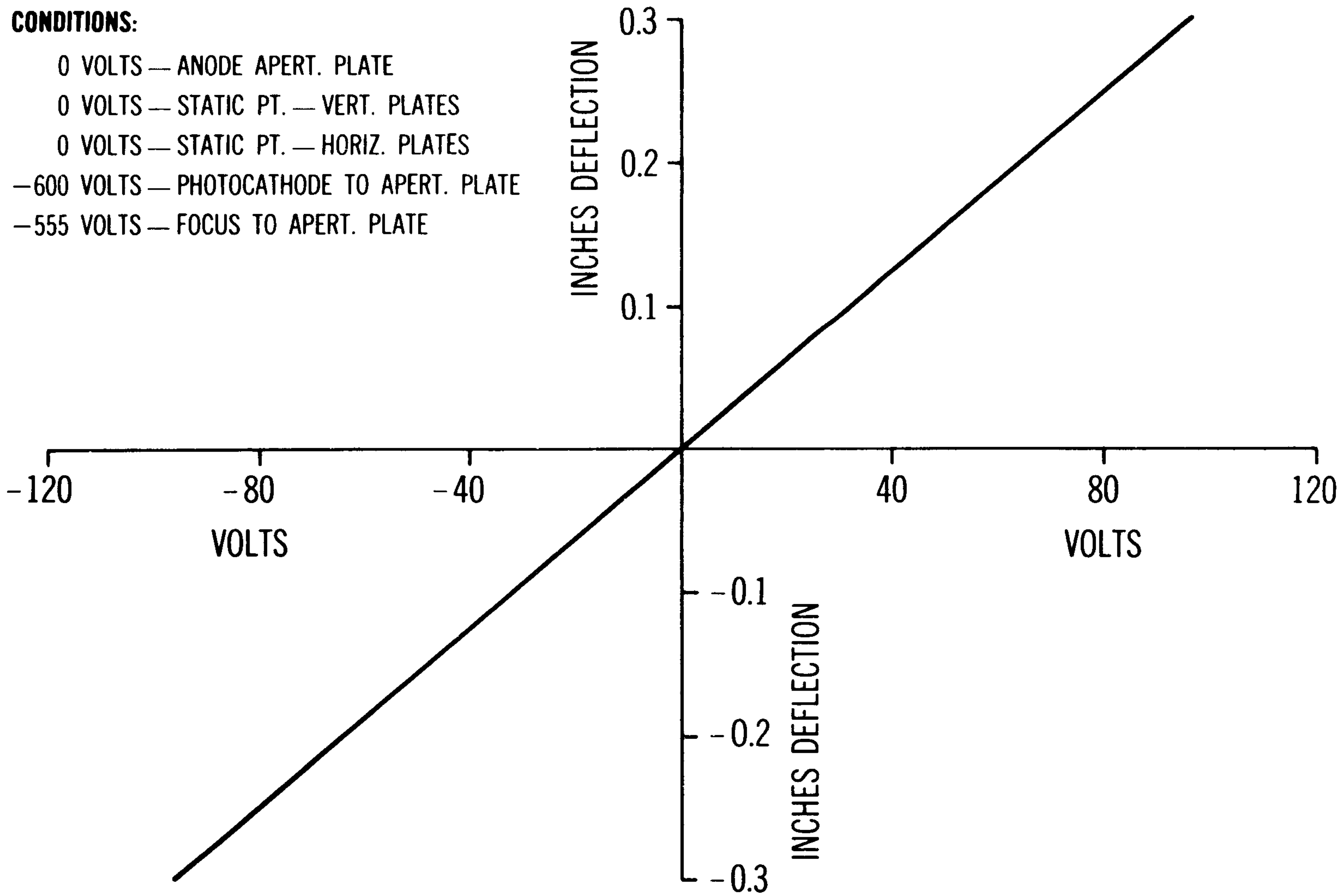


Figure 5

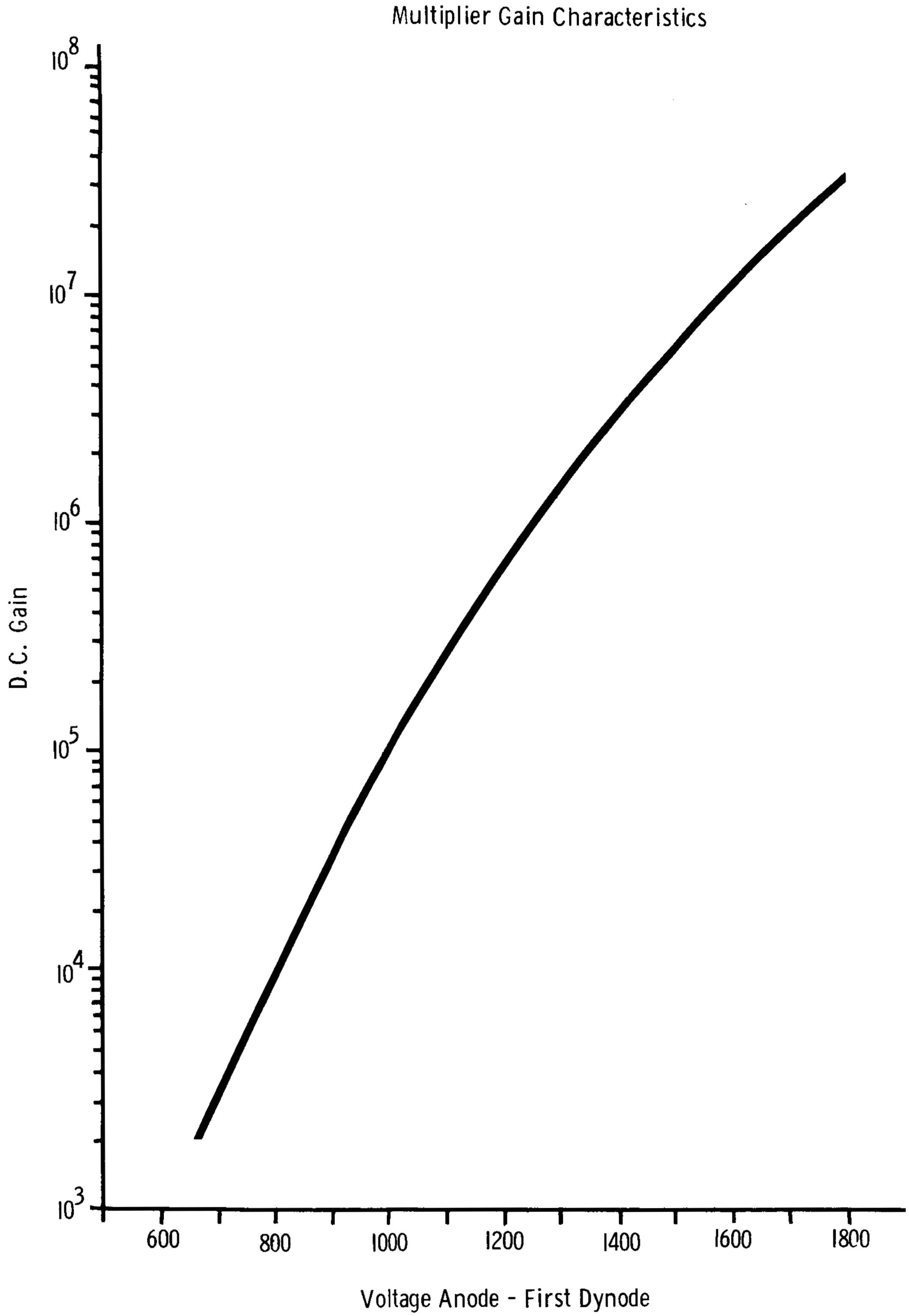

Multiplier Gain Characteristics
10^8
10^7
10^6
10^5
10^4
10^3
D.C. Gain
600
800
1000
1200
1400
1600
1800
Voltage Anode - First Dynode

Figure 6

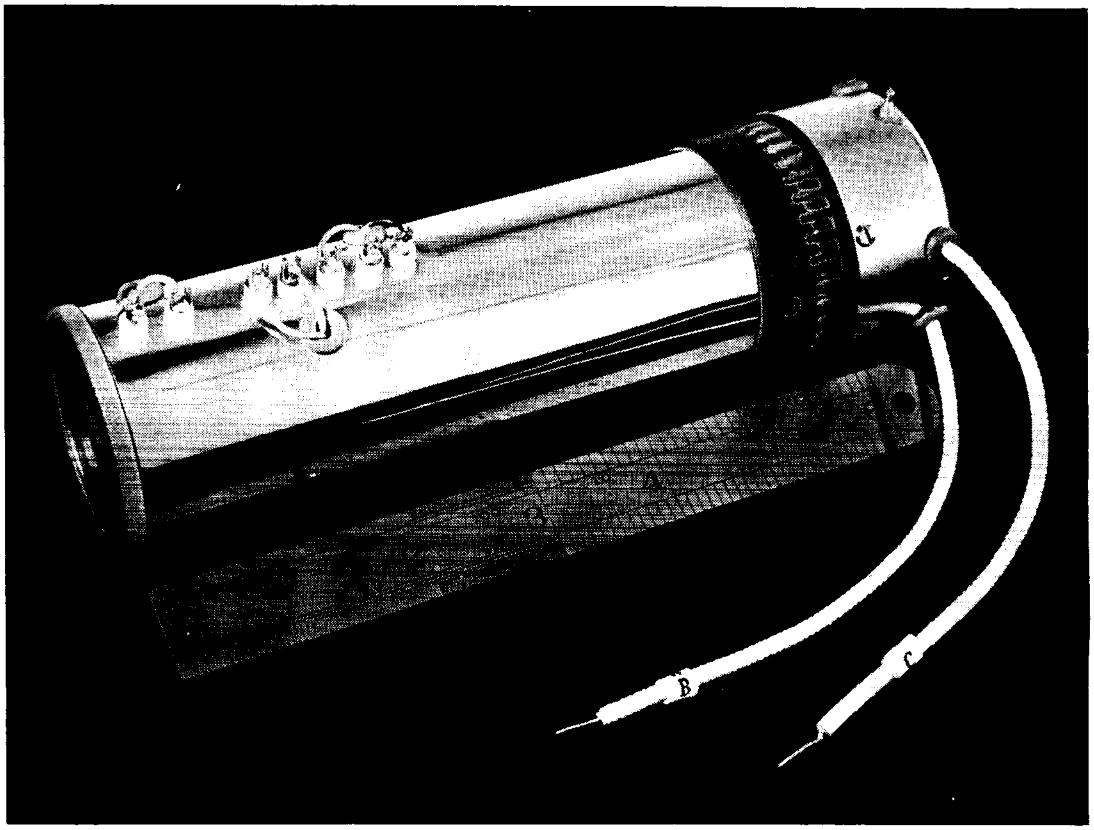


Figure 7

Encapsulated Image Dissector

Electronic Spot Size (at 20% Amplitude) vs. Displacement
at Photocathode

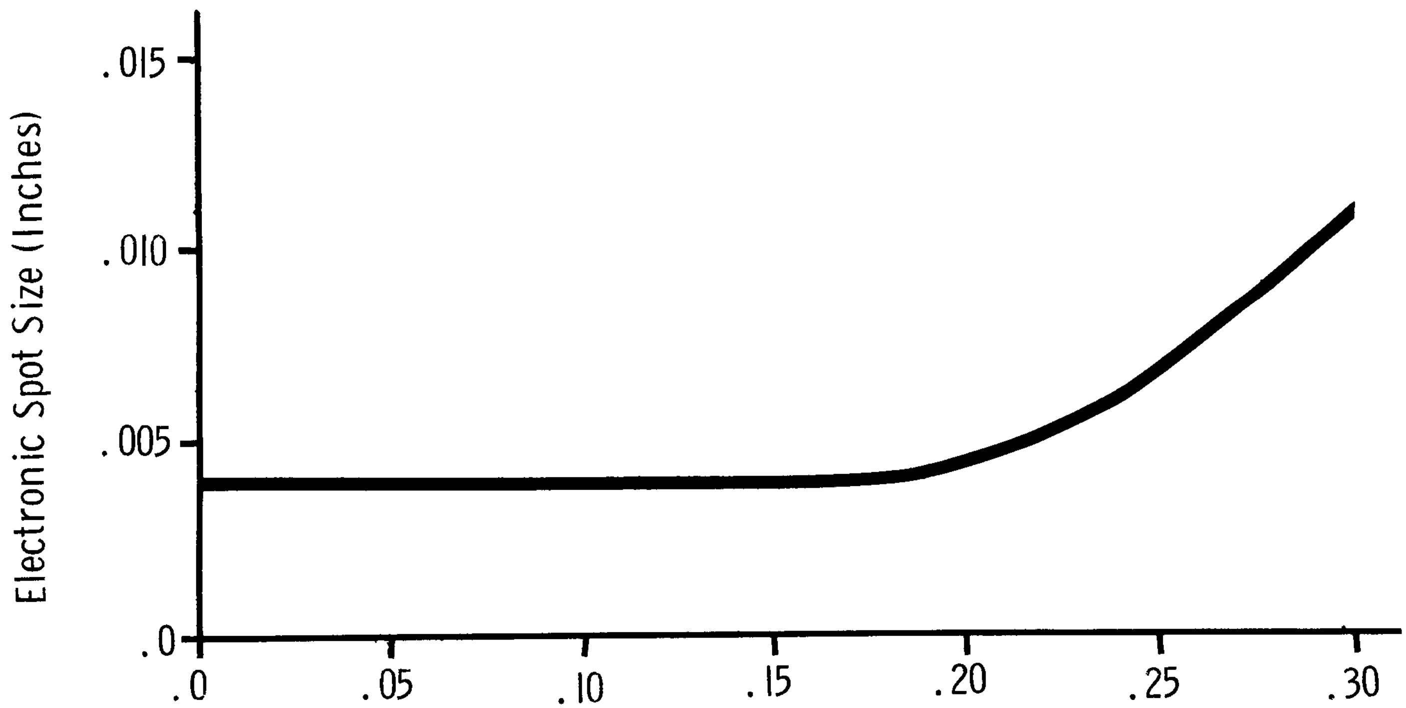


Figure 8

APPENDIX III

for

JPL SPECIFICATION NO. 31163 A

JPL SPECIFICATION NO. 31163 A

1. SCOPE

1.1 This specification covers the test requirements for an Electrostatic Image Dissector, to be utilized in the Attitude Control System for the Mariner C Spacecraft.

2. APPLICABLE DOCUMENTS

2.1 None

3. REQUIREMENTS

3.1 Conflicting Requirements - Any conflicting requirements arising between this specification and any other specification or drawing shall be referred in writing to the Jet Propulsion Laboratory (JPL) for interpretation and clarification.

3.1.1 Requests for Deviation - Any deviation from the requirements of this specification shall be considered a change or deviation and shall not be allowed except by written authorization from JPL.

3.2 Performance Characteristics

3.2.1 Reliability - The Image Dissector shall be capable of maximum reliability and continuous operation at one micro-ampere anode dc current output for a period of three years during which time performance shall be within limits established subsequently in this specification.

3.2.2 Spectral Response - The Image Dissector shall be furnished with an S-11 photocathode response.

3.2.3 Electron Aperture - The Image Dissector shall be furnished with a slit aperture 0.151 ±0.005 inch long and 0.012 ±0.002 inch wide with reference to the photocathode. The 0.151 inch axis of the slit shall be aligned with one axis of the deflection plates within 5°, and this set of deflection plates shall be referred to as the vertical deflection plates. This axis shall also be indicated by external marking on the tube photocathode. Orientation of the electron aperture with respect to the electron multiplier to minimize variation in output within the aperture as indicated in 4.1.5. (All dimensions in this specification are with reference to the photocathode.)

3.2.4 Electro-Mechanical Null Accuracy - The geometric center of the electron aperture, as referenced to the photocathode, with zero volts on the deflection plates, shall be within 0.030 inches of the mechanical center of the photocathode, as defined by the outside diameter of the cathode window outside ring.

3.2.4 Electron Multiplier - A twelve stage electron multiplier shall be incorporated in the Image Dissector. The electron multiplier shall have a gain of not less than one million, when operated at 125 volts per stage and a photocathode-to-anode voltage of 700 volts. Focus voltages shall be adjusted for optimum resolution.

3.2.6 Photocathode Sensitivity - The photocathode sensitivity shall be greater than 34 microamperes per lumen as measured at the photocathode. The photocathode shall be masked to define a useful area of 0.160 ±0.002 inches by 0.570 ±0.002 inches. The 0.570 inch dimension shall be parallel to the long electron aperture axis within

5° and shall be centered to within 0.005 inch radius (0.010 total indicator reading) with respect to the outer surface of the cathode electrode. Measurements shall be made using a source color temperature of 2870°K. The photocathode shall first be coated with tin oxide to eliminate voltage gradients within the fiber optics. The mask shall be formed with vacuum deposited aluminum with maximum transmission of 0.001. The mask and tin oxide overcoat shall be electrically connected to the photocathode.

3.2.7 Response Uniformity - With a constant input of 10^{-8} lumens at 2870°K concentrated in a spot 0.002 inch in diameter, no change in excess of 2:1 from the measured peak anode dc response shall be allowed when the spot is moved slowly across the useful area of the tube. This test shall be performed in accordance with 4.1.4 herein.

3.2.8 Focus - Focus shall be electrostatic. For all of the tests, focus voltage shall be held at one fixed voltage and shall not be "peaked" for focus vs. deflection. (All dimensions given herein are with reference to the photocathode).

3.2.9 Deflection - Internal symmetrical electrostatic deflection plates shall be provided which can deflect the focused electron image over a minimum of ±0.25 inch from the mechanical axis of the tube. Deflection sensitivity shall be greater than 0.0016 inches per volts (plate to plate) at 700 volts of accelerating potential. Linearity of electron image deflection as a function of deflection potential (voltage with respect to the electron aperture anode) shall be 1.0 percent. Long term (3 year) repeatability of electron image deflection shall be no greater than 0.002 inch anywhere within the useful area defined in 3.2 herein.

3.2.10 Fatigue - Long term (3 year) stability of the Image Dissector shall be such that the luminous sensitivity of the tube shall not change by more than 2:1, when illuminated with 10^{-8} lumens concentrated in a fixed position spot 0.002 inch in diameter on the photocathode anywhere within the useful area of 3.2. This requirement is presently waived and is considered a design goal.

3.2.10.1 Burn-In Test - In order to age the Image Dissector tubes at approximately Canopus input levels, the following test shall be performed for 100 hours or more:

a. Flood the photocathode with approximately 0.02 ft-candle of 2870°K illumination

b. Excite the tube with the following voltages:

(1) Photocathode to first dynode: 700 volts
(2) Last two dynodes: 125 volts per stage
(3) The remaining dynodes at such a voltage as to provide an output current of 0.1 microamp

Once determined at the start of the test, all voltages shall remain constant throughout the test period. Every 25 hours the anode current shall be measured and recorded. After completion of the burn-in, the tube must pass all other requirements of this specification.

3.2.11 Sensitivity - The overall Image Dissector, with an excitation of 10^{-8} lumens at 2870°K concentrated in a spot 0.002 inch in diameter, shall evidence a minimum dc signal current output of not less than 0.4 microampere when operated at a dynode voltage of 125 volts/stage and a photocathode-to-anode voltage of 700 volts. (Dark current is subtracted to determine the signal current output). Focus voltage is that required for maximum resolution.

3.2.12 Resolution - Image focus shall be adequate to assure that signal pulse width shall not be greater than 0.010 inch in addition to the electron aperture width when the photocathode is illuminated at any point in the useful area with 10^{-8} lumens at 2870°K concentrated in a spot 0.002 inch in diameter. Pulse width shall be measured between points where the signal is down to 20 percent of the peak signal amplitude. (All dimensions are referenced to the photocathode.)

3.3 Physical Characteristics

3.3.1 Dielectric Breakdown - The external electrical connections to the tube shall be designed to withstand a peak voltage of 3000 volts with no dielectric breakdown, either between connections or to support structure which may be grounded.

4. QUALITY ASSURANCE PROVISIONS

4.1 Functional Tests

4.1.1 Photocathode Sensitivity - Thepurpose of this test will be to evaluate the average sensitivity of the photocathode. The useful area of (3.2) the photocathode shall be fully illuminated with light at 2870°K. Illumination shall be 10 foot-candles. The cathode shall be operated at -30 volts and the focus electrode shall be operated at -27 volts with respect to the image aperture anode. The useful cathode current shall be measured as the difference between the cathode currents when the useful area of the cathode is illuminated and dark. The multiplier electrodes and the deflection plates shall be grounded. Useful cathode area is 6.35×10^{-4} ft.^{2} for computation of photocathode sensitivity.

4.1.2 Photocathode Response Uniformity - With the Image Dissector set up as in the foregoing test (4.1.1), the photocathode shall be illuminated with a spot of light 0.1 inch in diameter. This spot shall be moved slowly down the length of the useful area of the cathode and the photocathode current measured at spot center increments of 0.050 inch from -0.200 to +0.200 inches. There shall be no measurements less than 0.66 times the peak measured current. In each case the current measured shall be the difference between the current measured with the cathode illuminated and the cathode dark.

4.1.3 Multiplier Gain

a. Energize the Image Dissector with -700 volts photocathode and approximately -630 volts focus electrode (optimum focus) and ground all dynodes to the electron aperture. Illuminate the photocathode uniformity with approximately 10 ft.-candles, at 2870°K and measure the resultant active photocathode current (subtract any dark current). (See Figure 1)

b. Insert an aperture 0.004 inches in diameter and a filter (or filters) of transmission one percent (flat with wave length over the S-11 region) directly in front of the fiber optic faceplate and in the geometric center (being careful not to damage the fiber optic surface).

c. Illuminate the combination of 4.1.3 b. with 10 foot-candles (2870°K) and energize the image section as in 4.1.3 a. and additionally energize the multiplier section to 125 volts per stage (1500 total). Record the resultant anode current. (Subtracting dark current.)

d. Compute the multiplier gain by the following equations:

$$\text{Gain} = G = \frac{(I_4)\ (L_1)}{(I_1)\ (L_2)}$$

Where

L = Luminous input = ft/c x photocathode area (ft.^{2})

L_1= Luminous input of 4.1.3 a. =

$$\frac{(0.160)\ (0.570)}{144}\ (10) = 6.35 \times 10^{-3} \text{ lumens}$$

L_2= Luminous input of 4.1.3 b. = $\frac{T_3\ \pi(0.004)^2\ (10)}{4(144)}$=

= T_3 8.72 x 10^{-7} lumens

I_4= Anode Current of 4.1.3 d.

I_1= Cathode Current of 4.1.3 a.

T_3= Filter Transmission of 4.1.3 c.

R_c= Photocathode Response = $\frac{I_1}{L_1}$

The computed gain (G) shall not be less than 10^6.

4.1.4 Response Uniformity - With the full image dissector energized, the illumination level set for 10^{-8} lumens concentrated in a spot 0.002 inches in diameter. The spot shall be slowly moved over the useful area of the photocathode. Measurements of peak dc anode signal output shall be taken at the following combinations of positions:

a. Horizontal axis 0.000 ±0.045
b. Vertical axis 0.000±0.050, ±0.100, ±0.150. ±0.200, ±0.245

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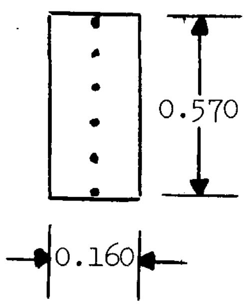
For these measurements the deflection plates shall be driven from suitable deflection amplifiers and sweep shall not be employed on either axis (except as necessary in locating the aperture). The positioning head shall be adjusted to each of the indicated positions of the spot on the photocathode and the deflection voltages adjusted to center electron image on the slit. The output levels shall be plotted on suitable graphed paper. No measured active anode current level shall be less than 50 percent of the peak measured current. The minimum dc signal current shall be greater than 0.4 microamperes.

4.1.5 Dynode Uniformity - The purpose of this test is to determine the variation in anode output versus electron image location at the electron aperture. For a constant input of 10^{-8} lumens imaged on the front surface of the fiber optic window, the electron image may be moved by energizing the vertical deflection plates. When the electron image is moved in such a manner anywhere, ($\pm$0.060 inches) along the vertical center line of the electron aperture referred to photocathode, the resultant minimum anode dc output shall not be less than 80 percent of the peak value attainable.

4.1.6 Resolution - With the test conditions as defined in 4.1.5a. sweep voltage of triangular waveform at 20 cps shall be applied to the horizontal deflection plates. The resulting signal waveform shall be observed on an oscilloscope. The pulse width between points at 20 percent of peak amplitude shall be measured at the center and at 0.050 inch increments along the center line of the long dimension of the slit. The focus voltage may be adjusted once on the axis of the tube at the start of the test to optimize the image focus. The measured pulse width shall not exceed 0.010 inch plus the width of the slit electron aperture (projected to the photocathode) at any of the 9 specific positions indicated below:



Active photocathode area nine points spaced in 0.050 inch increments from the center in either direction.

4.1.7 Leakage - The tube shall be energized as shown in Figure 2. Under these conditions there shall be no change in excess of two volts across any resistor when the tube is connected or disconnected from the bleeder (all connections). Measurements shall be made using an electrostatic voltmeter to avoid loading the circuitry. In addition, measured resistances between any one deflection plate and the remaining three, or to the image anode electrode shall not be less than 200 megohms when measured at 300 volts dc.

5. PREPARATION FOR DELIVERY

Not applicable

6. NOTES

Not applicable.